

MEMOIRS
OF THE
COLLEGE OF SCIENCE

KYOTO IMPERIAL UNIVERSITY

PHYSICAL
SCIENCE SOCIETY OF JAPAN

VOL. IV, No. 4

JUNE 1920

KYOTO

The Spectrum of Bromine Part I Line and Band Spectra, Lines of Arc and Spark Types and the Relations between the Lines

By

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(Received Oct. 20, 1919)

The Spectrum of bromine is not yet thoroughly studied. Structures of lines, Zeeman effect, regularities in the line spectrum, etc., are quite unknown. Berndt¹ attempted to investigate the Zeeman effect on the lines of this element, but he got no definite result owing to the faintness of the light emitted by his tube. Multiplicity of the spectrum was already noticed by Goldstein² and Nutting³, but their results were only fragmentary. The writer examined the spectrum of this element more minutely, and the result obtained will be given in the following pages. The present paper will deal chiefly with the line and the band spectra, lines of arc and spark types and certain relations among the lines. As to the structure of the lines and the Zeeman effect of certain lines including complex lines, a discussion will be offered in a separate paper.

One of the chief difficulties met with in this research was the preparation of a sufficiently intense source of light. As bromine vapour when ionized becomes very active, and electrodes are easily attacked, an ordinary Geisler tube could not be used. In the study of the spectrum of iodine⁴, tubes having outer tinfoil electrodes were

¹ Ann. Phys. (4) 8, 625, (1902).

² Verh. Deutsch. Phys. Ges. 9, 321, (1907).

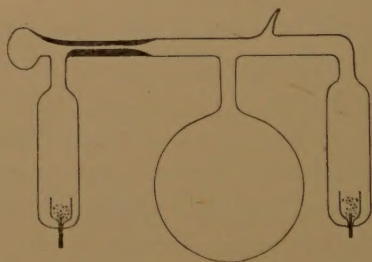
³ Astrophys. J. 19, 239, (1904).

⁴ Astrophys. J. 46, 183, (1917).

constantly used, and similar tubes were tried for bromine. This gave a fairly good result, but the intensity of the light emitted by such a tube was not sufficient for the present purpose. Next, tubes provided with thick platinum electrodes were tried. A carefully dried bromine was sealed in a very fine glass capillary having a very thin wall, and this was put in the discharge tube near one of the electrodes. The air was then thoroughly pumped out, and it was sealed off. A heavy discharge was then sent through the tube, which broke out the sealed capillary containing the bromine and filled up the tube with this vapour. The tube thus prepared was used as a bright source of light, but it was not easy to obtain a tube containing a proper amount of bromine. Besides this difficulty, the glass surrounding the electrodes was soon attacked by the active gas and the tube was soon spoiled.

Lastly, tubes provided with a bromine salt as electrodes were tried. A small quantity of a salt such as sodium bromide, potassium bromide, cadmium bromide, mercury bromide and silver bromide was put in a small glass cup having a platinum wire at bottom, and this was again sealed in an outer tube as shown in Fig. 1. Among the salts examined, silver bromide, owing to its relatively low melting point, gave a proper amount of bromine vapour, when an electric discharge was sent through. On the other hand, sodium bromide and potassium bromide gave a relatively small quantity of the vapour. Now, when tubes provided with such salt electrodes were sealed off from the pump, the vapour pressure of bromine was gradually increased as the discharge was going on, and the light emitted from the tube suffered a corresponding change. To reduce this change a one litre flask was connected to the main tube in order to increase the whole volume of the tube and this proved to be satisfactory. The form of the tube finally adopted is of the form shown in Fig. 1, in which the capillary part had a diameter about 0.2-0.3 mm. and 2 cm. in length. As salt electrodes, silver bromide was generally used, but in some cases sodium bromide and potassium bromide were employed. These tubes were excited by a 20 cm. induction coil, and an exceedingly bright light was obtained in an end-on direction.

FIG. 1.



The colour of this light varied with the vapour pressure and the current density. With a very low pressure, a bluish green light was emitted from the capillary part, while the wide part of the tube was filled up with a glow of a chamois yellow colour. When the vapour pressure was made to increase, the latter changed to a pink glow, and at the same time, a deep pink light took the place of the bluish green light in the capillary. The light emitted from the capillary portion consisted chiefly of the line spectrum of bromine, and the glow of chamois yellow in the wide tube gave up a mixture of lines and bands.

Line and Band Spectra

As shown above the light emitted from the capillary portion of the tube suffered a change in colour from a bluish green to a deep pink, when the vapour pressure was made to increase. This change was studied with a spectrograph having a good replica grating; the dispersion on a photographic plate being 0.033 mm. at $\lambda 4900$ Å. in the first order spectrum. The photographic plates used were the Wratten panchromatic and exposures of about twenty minutes were given to obtain good negatives. If a change in the colour of the discharge was noticed at the end of the exposure, the plate used was rejected. Photographs thus obtained are reproduced in Fig. 2 and Fig. 3, PL. I. It will be observed that the spectrum of the pink discharge consists of a much greater number of lines than that of the bluish green, and further that the former contains almost all the lines of the latter.

The intense lines belonging to the blue spectrum lie under $\lambda 480 \mu\mu$, while in the pink spectrum a number of strong lines are distributed over the entire visible spectrum. A closer examination shows, however, that a few lines in the blue spectrum reduce their intensities as the spectrum changes to pink. The intense lines belonging to these spectra are given in Table I, where the wave lengths were taken from Kayser's Spectroscopy. It will be seen that four strong lines in a red region, i.e., $\lambda\lambda 6632, 6560, 6351, 6150$, and two bright lines in blue $\lambda\lambda 4478, 4473$ are characteristic lines of the pink spectrum. There are, however, a number of intense lines common to the both spectra, i.e., $\lambda\lambda 4930, 4928, 4817, 4785, 4767, 4743, 4720, 4705, 4679, 4623$ and 4365 , etc. Lines at $\lambda 4508$ and $\lambda 4261$, though not strong in the blue spectrum, disappeared entirely from the pink one.

TABLE I

Wave lengths	Relative Intensities in Blue Spectrum	Relative Intensities in Pink Spectrum (cap)	S spark line A arc line	* Weakened by Spark	C Complex line	Wave lengths	Relative Intensities in Blue Spectrum	Relative Intensities in Pink Spectrum (cap)	S Spark line A Arc line	* Weakened by Spark	C Complex line
6632.02	0	3	A	*	C	4780.52	0	6		*	
6582.52	0	1				4777.30	4	5	S		
6560.17	0	5	A	*	C	4774.01	1	3			
6545.00	0	1				4767.28	7	7	S		
6351.02	0	10	A	*	C	4752.47	0	6		*	
6149.95	0	10	A	*	C	4742.87	7	7	S		
5940.83	0	1		*		4735.67	4	5	S		
5852.40	0	1		*		4728.49	3	5	S		
5831.04	1	2				4720.56	8	8	S		
5719.17	0	1				4705.00	10	10			C
5711.25	0	1				4693.48	4	5			C
5600.90	0	0				4678.89	10	10	S		
5590.15	1	1				4673.56	3	5			C
5506.97	f	2				4652.18	3	4	S		
5495.24	f	2				4644.17	3	5	S		
5489.00	f	2									
5466.43	0	2	A	*	C	4629.66	3	3			
5450.28	0	2				4622.99	8	8	S		
5442.55	0	1				4614.86	0	5		*	
5435.30	0	1				4605.90	2	4	S		
5425.21	0	1				4575.95	2	6		*	
5423.01	0	2				4543.12			S		
5395.69	0	3	A	*	C	4542.67	4	5			
5345.53	0	2	A	*	C						
5335.30	0	1				4538.95	2	4			
5332.49	2	8	S			4530.00	1	5		*	
5304.31	1	6	S			4525.82	0	9	A	*	
5272.89	0	1				4513.99	3	5		*	
5263.68	0	1				4508.29	3	0	S		
5238.47	2	8	S			4490.68	0	4		*	
5227.91	0	1				4477.96	0	10	A	*	
5194.07	0	2				4472.83	0	10	A	*	
5182.57	3	8	S			4441.93	0	8	A	*	
5164.56	1	5	S			4425.32	0	5	A	*	
5143.63	0	0				4407.80	0	0			
5054.85	1	3				4399.87	0	1		*	
5038.96	0	1				4365.76	8	10	S		
4979.95	1	5	A	*	C	4291.54	2	6	S		
4959.51	1	3				4261.44	3	0	S		
4945.77	1	3				4237.00	1	4	S		
4942.21	1	0				4224.00	7	10	S		
4930.82	10	10	S			4193.62	1	5	S		
4928.97	10	10	S			4179.76	2	6	S		
4921.39	2	5				4140.37	1	4	S		
4867.94						4135.79	1	4	S		
4866.85	2	4	S			4117.58			S		
4848.99	5	5									
4845.20	1	3	S								
4816.90	10	10			C						
4807.80	3	5			C						
4785.64	10	10			C						

Next, the colour of the glow in the wider portion of the tube varied also with the vapour pressure of bromine. With a small pressure the glow showed a chamois yellow colour, but it soon changed to a pink when the vapour pressure was made to increase above a certain point. The spectrum of this pink glow differs somewhat from that of the pink light in the capillary. To compare these, the lights coming from both portions of the tube were photographed with a small prism spectroscope, and spectrograms thus obtained were shown in Fig. 4, PL. I.

We see that there is a selective reduction of intensity in certain lines of the spectrum of the glow in the wide tube. Among these, the reduction of the intensity is especially strong in the following lines :

λ 5332, 5304, 5238, 5183, 4931, 4929, 4868, 4867, 4743, 4623, 4543, 4542, 4292, 4237, 4140, 4136.

Thus the spectrum of the light emitted by the glow in the wide part of the discharge tube is much simpler than that of the light from the capillary. This seems to suggest that new centers of light emission were produced by the discharge as it passed from a wider part to the capillary, where both the electric field and the current density were stronger. We have thus three types of the line spectrum of bromine, one blue and two pink.

Beside these, we have a band spectrum emitted from the glow in a wide part of the tube. If the vapour pressure was sufficiently low, the colour of this glow was chamois yellow, the spectrum of which consisted of lines and bands. This band spectrum began nearly at λ 500 $\mu\mu$, and extended farther up to λ 660 $\mu\mu$ or more, and it showed a fluted appearance like that of the iodine band in a similar region. The heads of each band turned toward the violet side and more than twenty five of them could easily be seen on a photographic plate. This channelled band spectrum was always obtained whenever silver bromide or sodium bromide was used as electrodes, so that we should attribute the origin to bromine. A low vapour pressure and a small current density were necessary conditions for production of this band spectrum, and it disappeared almost entirely when the pressure exceeded a certain point.

The tube used for the study of this band spectrum had instead of a capillary, an ordinary tubing of a diameter of about 3 mm. and a length of 15 cm. and this was connected to a pump during exposure

to a spectrograph to remove the excess of the bromine vapour produced by the discharge. The channelled spectrum emitted by such a tube was photographed with a three-prism spectrograph provided with a photographic objective of one meter focus, the time of the exposure being about five hours. The linear dispersion was not sufficient to separate the lines composing the band spectrum, and it was difficult to determine the wave lengths of heads as they were not so sharp to be measured.

The relation of this band spectrum to the absorption spectrum of bromine vapour was also studied with the same instrument. The light from the crater of a carbon arc was projected through a bulb containing bromine vapour on the upper half of the slit of the above spectrograph and the absorption spectrum was thus photographed. Then the lower half of the slit was illuminated from the light coming from the above tube and the emission band was thus recorded on the same plate. In this case, the difficulty was experienced of keeping the tube from cracking to the end of the exposure, more than a dozen plates being spoiled as the tube got cracks. The photograph reproduced in Fig. 5, PL. I is not a good one, but it will be sufficient to show the general features of both spectra. Here *a* and *b* were taken on one plate, and *c* on another.

Now, according to Eder and Valenta¹, lines in the emission band coincide closely enough with those of the absorption band determined by Hasselberg, but not exactly. The results obtained by the writer are not, however, in harmony with those obtained by them. As the writer is not able to consult their original papers, it is not certain that we are dealing with the same band but the plate shows that the emission and absorption spectra do not correspond even in general appearance. In the present experiment, as the dispersion was insufficient, the coincidence of line to line could not be examined, a further study on this point is necessary, and conclusion is reserved.

Lines of Arc and Spark Types

As described above we have, according to the conditions of the discharge, one blue and two pink spectra of bromine. The pink spectrum emitted by the glow in the wide part of the tube required less energy to be excited, because the current density and the poten-

¹ Kayser. Spectroscopy V. p. 188.

tial gradient would both have smaller values in comparison with those in the constricted portion of the tube.

This will lead us to classify the stronger lines in this pink spectrum as lines of the arc type. Comparing this with the blue spectrum we see that certain stronger lines in the former have disappeared entirely from the latter, and at the same time a number of faint lines in the pink spectrum are enhanced in the blue. This difference in the spectrum will be due to the electric conditions in the corresponding glows, and it is evident that much energy will be required to excite the latter type of line. The insertion of a spark gap in the discharge circuit caused the pink glow in the capillary to change into the blue one. It is then natural to regard the lines enhanced in passing from the pink to the blue spectrum as lines of the spark type. The pink spectrum emitted from the capillary contains both kinds of lines, and shows an intermediate stage of the transition from one to the other.

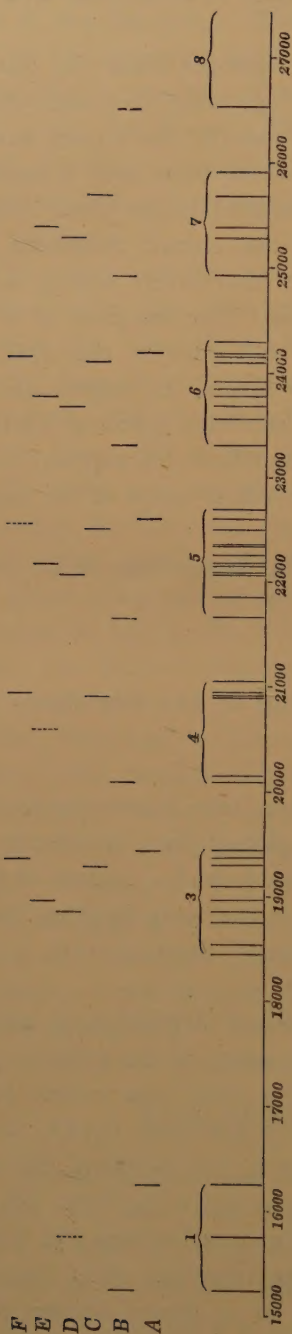
The above Table I gives some of the strong lines of the arc and spark types.

Certain Relations in the Lines of the Bromine Spectrum

Lines belonging to the arc type have very interesting properties. If the wave lengths of these lines are plotted on a coordinate paper, it will be observed that they are divided into a system of groups. If the wave numbers are used instead of the wave lengths, the relation becomes more evident. They arrange themselves in a nearly equal interval with a roughly equal width.

Counting from the red, three lines at $\lambda\lambda 6560, 6351$ and 6150 form the first group having the width of 1017 , in the scale of $1/\lambda$, the second group seems to be missing, the third one comes between $\lambda 5423$ and $\lambda 5144$, the fourth between $\lambda 4980$ and $\lambda 4752$, the fifth within $\lambda 4615$ and $\lambda 4408$, and the sixth lies between $\lambda 4291$ and $\lambda 4118$. The widths of the above groups are $1017, 1002, 961, 1018$ and 984 in the scale of $1/\lambda$, and the distances between the first lines of each group are $2 \times 1598, 1641, 1589, 1633$ and 1619 respectively in the same scale. Here the first line of a group denotes the line lying at the red end of the group.

FIG. 6



As the lines recorded in our plates ended nearly at $\lambda 4100$, we could not proceed farther, but the two lines at $\lambda 4103$ and $\lambda 3857$ having an interval of 1004 may be found in the table of the wave lengths given by Eder and Valenta¹. The first of them is situated at a distance of 1601 from the corresponding one of the sixth group. Further, one line at $\lambda 3770$ may be selected at a distance of 2×1610 from the first line of the sixth group, suggesting that this is the corresponding line of the eighth group. The table of the above authors ceases at $\lambda 3685$, so that we can not proceed farther.

The grouping of the line is illustrated in Fig. 6, and their wave lengths are given in Table II.

These groups of lines may also be analysed into systems of lines having approximately constant frequency differences, and they are given in Table III.

Lastly, it is desirable to note that the following pairs of lines having constant frequency differences may be picked out from the table.

¹ Kayser's Spectroscopy V.

TABLE II

Group No.	λ	$\frac{1}{\lambda}$	Group widths.	Group distances.
1.	$\left\{ \begin{array}{l} 6560.17 \\ 6351.02 \\ 6149.95 \end{array} \right.$	$\left\{ \begin{array}{l} 15243.5 \\ 15745.5 \\ 16260.3 \end{array} \right.$	$\left\{ \begin{array}{l} 1016.8 \end{array} \right.$	$\left\{ \begin{array}{l} 3196.4 \\ = 2 \times 1598.2 \end{array} \right.$
3.	$\left\{ \begin{array}{l} 5423.01 \\ 5395.69 \\ 5332.49 \\ 5304.31 \\ 5272.89 \\ 5238.47 \\ 5182.57 \\ 5164.56 \\ 5143.63 \end{array} \right.$	$\left\{ \begin{array}{l} 18439.9 \\ 18533.3 \\ 18751.1 \\ 18852.6 \\ 18964.9 \\ 19089.5 \\ 19295.4 \\ 19362.7 \\ 19441.5 \end{array} \right.$	$\left\{ \begin{array}{l} 1001.6 \end{array} \right.$	$\left\{ \begin{array}{l} 1640.6 \end{array} \right.$
4.	$\left\{ \begin{array}{l} 4979.95 \\ 4959.51 \\ 4785.64 \\ 4780.52 \\ 4774.01 \\ 4752.47 \end{array} \right.$	$\left\{ \begin{array}{l} 20080.5 \\ 20163.2 \\ 20895.8 \\ 20918.2 \\ 20946.7 \\ 21041.7 \end{array} \right.$	$\left\{ \begin{array}{l} 961.2 \end{array} \right.$	$\left\{ \begin{array}{l} 1588.6 \end{array} \right.$
5.	$\left\{ \begin{array}{l} 4614.86 \\ 4575.95 \\ 4530.00 \\ 4525.82 \\ 4513.99 \\ 4508.29 \\ 4490.68 \\ 4477.96 \\ 4472.83 \\ 4441.93 \\ 4425.32 \\ 4407.80 \end{array} \right.$	$\left\{ \begin{array}{l} 21669.1 \\ 21853.4 \\ 22075.1 \\ 22095.4 \\ 22153.4 \\ 22181.4 \\ 22268.3 \\ 22331.6 \\ 22357.2 \\ 22512.7 \\ 22597.2 \\ 22687.1 \end{array} \right.$	$\left\{ \begin{array}{l} 1018.0 \end{array} \right.$	$\left\{ \begin{array}{l} 1632.6 \end{array} \right.$
6.	$\left\{ \begin{array}{l} 4291.54 \\ 4237.00 \\ 4224.00 \\ 4206.23 \\ 4193.62 \\ 4179.76 \\ 4151.52 \\ 4140.37 \\ 4135.79 \\ 4117.58 \end{array} \right.$	$\left\{ \begin{array}{l} 23301.7 \\ 23601.6 \\ 23674.2 \\ 23774.3 \\ 23845.7 \\ 23924.8 \\ 24087.6 \\ 24152.4 \\ 24179.2 \\ 24286.1 \end{array} \right.$	$\left\{ \begin{array}{l} 984.4 \end{array} \right.$	$\left\{ \begin{array}{l} 1619.2 \end{array} \right.$
7.	$\left\{ \begin{array}{l} 4012.70 \\ 3955.50 \\ 3939.86 \\ 3891.79 \\ 3857.36 \end{array} \right.$	$\left\{ \begin{array}{l} 24920.9 \\ 25281.2 \\ 25381.6 \\ 25695.1 \\ 25924.5 \end{array} \right.$	$\left\{ \begin{array}{l} 1003.6 \end{array} \right.$	$\left\{ \begin{array}{l} 1601.4 \end{array} \right.$
8.	$\left\{ \begin{array}{l} 3770.41 \end{array} \right.$	$\left\{ \begin{array}{l} 26522.3 \end{array} \right.$		

TABLE III

SERIES A

Line Number	λ	$\frac{1}{\lambda}$	Differences.
1.	6149.95	16260.3	$ \begin{aligned} &1594.0 \\ &1587.2 \\ &3155.7 \\ &= 2 \times 1577.9 \\ &1582.0 \end{aligned} $
2.	5600.90	17854.3	
3.	5143.63	19441.5	
4.	—	—	
5.	4425.32	22597.2	
6.	4135.79	24179.2	

SERIES B

Line Number	λ	$\frac{1}{\lambda}$	Differences.
1.	6560.17	15243.5	$ \begin{aligned} &4837.0 \\ &= (3 \times 1612.3) \\ &1630.8 \\ &1590.4 \\ &1619.2 \\ &1601.4 \end{aligned} $
2.	—	—	
3.	—	—	
4.	49799.5	20080.5	
5.	46059.0	21711.3	
6.	42915.4	23301.7	
7.	40127.0	24920.9	
8.	37704.1	26522.3	

SERIES C

Line Number	λ	$\frac{1}{\lambda}$	Differences.
1.	—	—	$ \begin{aligned} &1622.8 \\ &1594.5 \\ &1574.9 \\ &1607.5 \end{aligned} $
2.	—	—	
3.	5182.57	19295.4	
4.	4780.52	20918.2	
5.	4441.93	22512.7	
6.	4151.52	24087.6	
7.	3891.79	25695.1	

SERIES D

Line Number	λ	$\frac{1}{\lambda}$	Differences.
1.	—	—	
2.	—	—	
3.	5304.31	18852.6	3222.5 $= (2 \times 1611.2)$
4.	—	—	
5.	4530.00	22075.1	
6.	4224.00	23674.2	
7.	3955.50	25281.2	

SERIES E

Line Number	λ	$\frac{1}{\lambda}$	Differences.
1.	—	—	
2.	—	—	
3.	5274.89	18964.9	1610.4 1606.1 1592.9 1607.3
4.	4860.19	20575.3	
5.	4508.29	22181.4	
6.	4206.23	23774.3	
7.	3939.86	25381.6	

SERIES F

Line Number	λ	$\frac{1}{\lambda}$	Differences.
1.	—	—	
2.	—	—	
3.	5164.56	19362.7	1584.0 1620.9 1584.8
4.	4774.01	20946.7	
5.	4431.13	22567.6	
6.	4140.37	24152.4	

TABLE IV

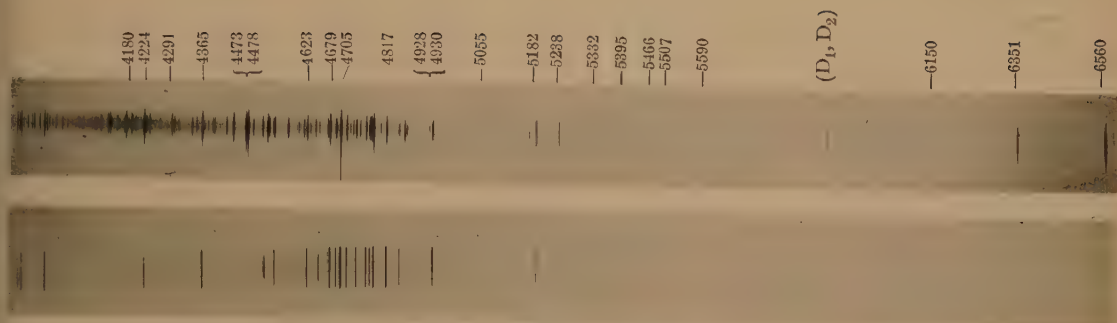
Pairs having Constant Frequency Differences		
λ	$\frac{1}{\lambda}$	Differences
4151.52 3891.79	24087.6 25695.1 >	1607.5
4224.00 3955.50	23674.2 25281.2 >	1607.0
4860.19 4508.29	20575.3 22181.4 >	1606.1
4206.23 3939.86	23774.3 25381.6 >	1607.3
4224.00 3955.50	23674.2 25281.2 >	1607.0
6149.95 5600.90	16260.3 17854.3 >	1594.0
4780.52 4441.93	20918.2 22512.7 >	1594.5
4508.29 4206.23	22181.4 23774.3 >	1592.9
5600.90 5143.63	17854.3 19441.5 >	1587.2
5164.56 4774.01	19362.7 20946.7 >	1584.0
4431.13 4140.37	22567.6 24152.4 >	1584.8

Summary

1. Sources of light giving bright line spectrum of bromine were described.
2. Bromine emits the light in blue and pink glows, and the corresponding spectra were studied.
3. The relation of the emission band to the absorption spectrum was discussed.
4. Lines in the spectrum of bromine were classified into the arc and the spark types.
5. Among the arc lines, certain relations were found.
6. Pairs of lines having constant frequency differences were found.

In conclusion, the writer wishes to express his thanks to Prof. T. Mizuno for the interest he has taken in this work.

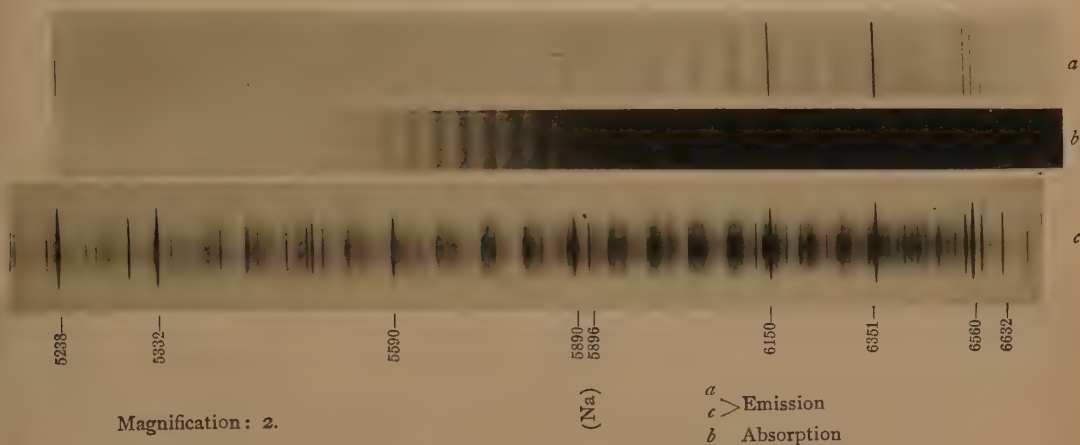
Fig. 2 (Pink discharge)



Magnification : 1.7

Fig. 3 (Blue discharge)

Fig. 5 (Bromine Band Spectrum)



Magnification : 2.

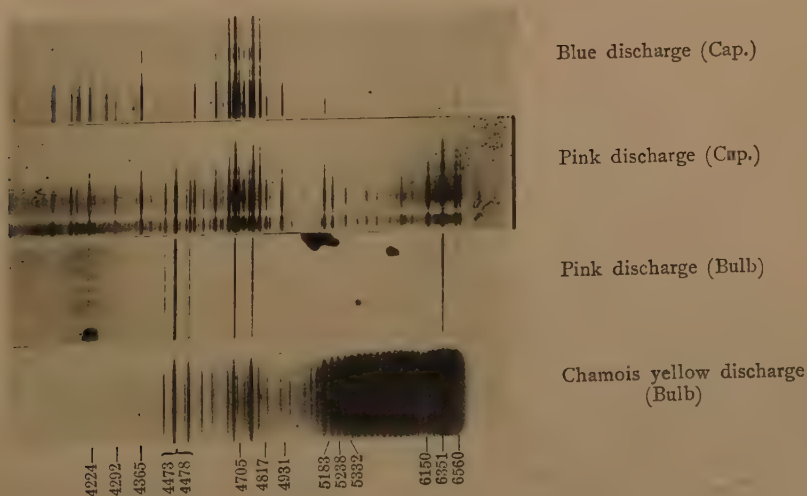


Fig. 4

Magnification : 3.5

The Spectrum of Bromine Part II

Line Structures and the Zeeman Effect

By

Masamichi Kimura

(Received Oct. 20, 1919)

In the first communication, the results of the investigation on the line and band spectra of bromine were given. In this paper the structures of lines and the Zeeman effect on certain lines studied with an echelon grating will be discussed. More than ten lines were found to have complex structures, and the behaviour of such lines in different magnetic fields were examined. The resolving power of the instrument was not quite sufficient, and further investigations are desirable to draw final conclusions.

The echelon used in this work was one made by Hilger with forty plates, 1 cm. thick, in optical contact. This was mounted between a collimator and a telescope, each of 45 cm. focus. The telescope of this focus is too short for the photographic work and an objective of three meter focus was ordered from Brashear Co. two years ago, and a preliminary research was started with a telescopic objective of one meter focus. The long focus objective has not yet arrived, and I should like to resume the experiments on the arrival of the said objective.

The echelon and the objectives of the collimator and the telescope were enclosed in a wooden box, and the temperature within this enclosure was kept constant to within $0^{\circ}.1$ C by a toluole thermostat. The slit of the collimator was removed and its place was taken by the second slit of a Hilger constant deviation spectroscope used as a

monochromator. The adjustment of the slit was done in a similar way to that in the work on iodine¹.

The four strong lines in the red, and a few lines in the other region were studied with this arrangement. In some cases, however, two lines were so close together that the second slit of the monochromator could not stop one of them. To overcome this difficulty, the constant deviation spectroscope was dispensed with and a big direct vision prism consisting of five elements was placed between the objective of the telescope and the echelon, the dispersion of the prism being vertical, while that of the echelon was horizontal. The echelon slit was then reduced in length to about a fraction of a millimeter by sliding a v-shaped diaphragm. With this arrangement it was possible to photograph with the echelon the entire bromine spectrum from red to violet on a single plate, the spectrum appearing as a vertical column consisting of short lines. A photograph of a portion of the spectrum taken with this combination is shown in Fig. 1. PL. I.

The tubes employed were of the same type as those described in the previous paper. The end-on emission from the capillary part was so bright that a few minute's exposure gave a good impression of strong lines on Wratten panchromatic plates.

Line Structures

In the case of the study of the four strong lines in red, the constant deviation spectroscope was used in combination with the echelon spectroscope. In all of these lines, the widths of the components were less than the distance between the successive orders in the spectrum formed by the echelon. The echelon was always adjusted so as to show the strongest component in the position of double order. In the following the strongest line is designated by 0.000 and the distances of the other components from this zero position are indicated, the minus sign showing the side of short wave length.

The following lines showed the structures:

- $\lambda 6632$. This line has three components decreasing in both intensity and separation toward the side of short wave length. The components are 0.000, -0.080 and -0.138, the latter being broad and suggesting some structure.
- $\lambda 6560$. This line has a similar structure to the above line, their components being 0.000, -0.080 and -0.143.

¹ *Astrophys. J.* 46, 197 (1917).

- $\lambda 6351$. The line consists of three components at 0.000, -0.069 and -0.143.
 $\lambda 6150$. This line has a similar structure to $\lambda 6632$; the third component seems to be a very close doublet. Components are at 0.000, -0.068 -0.126 and -0.147(?)
 $\lambda 5466$. Very close doublet.
 $\lambda 5396$. Double lines; 0.000, -0.086.
 $\lambda 5346$. Very close doublet.
 $\lambda 4980$. Very close doublet.
 $\lambda 4817$. This line is not clearly resolved, but three components were seen through some background. They are at 0.000, -0.036 and -0.068 approximately.
 $\lambda 4808$. Double? Very faint.
 $\lambda 4786$. This line has a similar structure to $\lambda 4817$.
 $\lambda 4705$. This line has a complex structure, perhaps a triplet, but not resolved distinctly.
 $\lambda 4693$. Doublet?
 $\lambda 4674$. Doublet.

Lines lying on the violet side of $\lambda 4600$ have not yet been studied, but it is worthy of mention that all of the complex lines described above belong to lines of the arc type of bromine.

The enlarged reproductions of the first four lines are shown in Fig. 2, PL. I.

Zeeman Effect of Complex Lines

The tubes employed in this part of the investigation were of the same type as that described in the previous paper. The short capillary part of the tube was mounted between flat pole pieces of an electromagnet of a Bu-Bois type, the field being homogeneous in the region of the capillary. The tube was observed end-on, i.e., in a direction perpendicular to the lines of force. As a double-image polarizing prism a natural crystal of Iceland Spar about 1.0 cm. thick was used. This was placed close to the capillary, and when properly oriented, gave two polarized images very close together, one immediately above the other. These images were formed on the first slit of the Hilger constant deviation spectroscope by means of a Zeiss Tessar.

These images were about a millimeter in diameter, and were separated by a distance of about 3 mm. Both polarized components could thus be photographed with the echelon simultaneously, and by raising the images about 1.5 mm. on the slit, we could obtain two more records showing the magnetized lines in coincidence with unmagnetized ones. The vertical shift of images was effected by slightly rotating round a horizontal axis a piece of a plane parallel glass plate

1 cm. thick, just as was done in the work on iodine¹. The field strengths were determined by a bismuth spiral. Wratten panchromatic plates were generally used, and an exposure of about twenty minutes was enough to secure a good negative for unmagnetized lines. The following four lines were studied with this arrangement:

$$\lambda\lambda 6632, \quad 6560, \quad 6351, \quad 6150.$$

$\lambda 6632$ (Fig. 4, PL. II)

This line consists of three components decreasing in both intensity and separation toward the side of short wave length. Denoting the first well defined line as 0.000, the components are located at -0.080, and -0.138, the latter being broad and suggesting some structure.

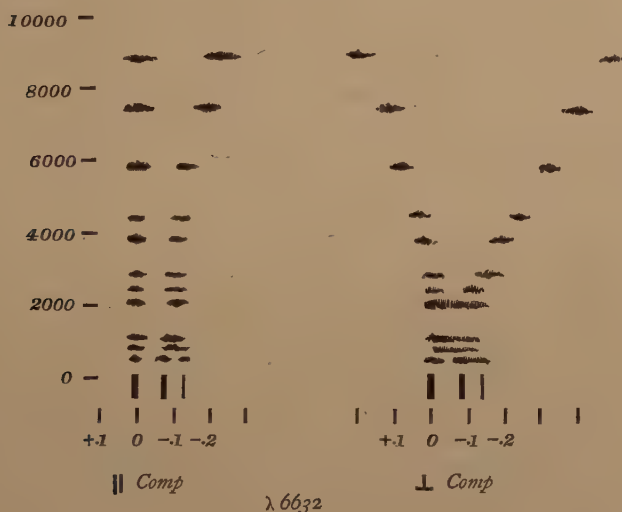
We will now consider first the behaviour of the component of vibration parallel to the field. In the case of a normal Zeeman effect the parallel component remains unaffected by the field, but in the line under consideration, its second and third components were so sensitive that even weak fields of several hundred gauss modified the appearance of the line. At the field of five hundred gauss all the components got broader, and the second and the third members mutually approached to a slight extent, and they fused, when the field was raised to one thousand gauss, into a single broad line situated midway between them. The line thus formed then approached towards the main line until the field strength reached to about three thousand gauss, and then separated again, the centre of the broadened main line lying almost at the original position in the zero field. The whole course of the changes followed by the components of the line is shown in Fig. 3.

Next, the perpendicular component of the vibrations was affected in a more complex way. It was difficult to interpret the plates taken below 3000 gauss, as the components were too hazy, though slight patches of light were noticed at certain points on a somewhat continuous background. From these patches the behaviour of the components may be supposed as follows: the main line was decomposed into two components, the negative branch of which fusing the satellites gave a single component in a strong field. At fields higher than

¹ *Astrophys. J.* 46, 197 (1917).

2500 gauss two broad components were always observed, the component situated on the short wave length side forming a strongly displaced branch. This greater shift of the one branch of the main line here observed seems to occur always when it fused with an approaching satellite, and this may be considered as one of the characteristic features in the Zeeman effect of complex lines. A similar phenomenon was observed in the case of other lines.

FIG. 3.



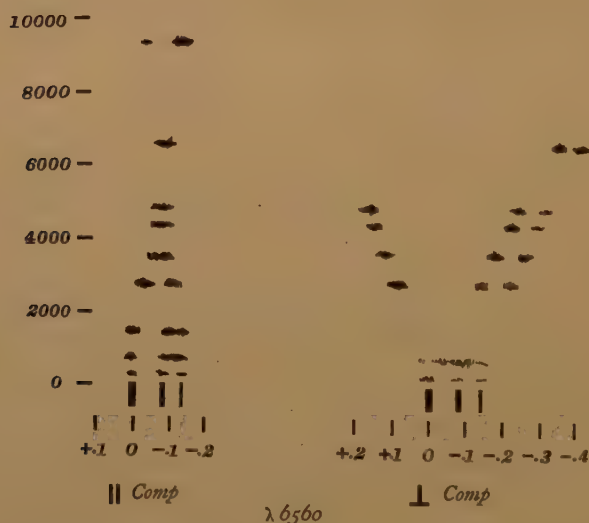
$\lambda 6560$ (Fig. 5. PL. II)

This line has three components similar to $\lambda 6632$ at 0.000 - 0.080 and -0.143. The behaviour of this line was studied up to a field of 9500 gauss. In the parallel component the main line showed only broadening up to the field of 1500 gauss. The wings produced on the two satellites touched at about 750 gauss. They looked to have been fused into one at 1500 gauss and from that field the main component began to approach toward the satellites. At 2700 gauss a single broad band, as the result of the fusion of the two components, was observed, the center of this line displaced toward the short wave length side as the field was increased up to 6500 gauss. A birth of a faint component on the long wave length side was noticed

at the field of 8500 gauss, the distance between it and the mother line being about $0.097 \text{ \AA}$ at 9500 gauss.

In the perpendicular component, three broad ones were seen at the field of 250 gauss. As the field was increased to 700 gauss, one component almost coinciding in position with the main line and one broad component just touching the former and occupying the position of the two satellites were observed; this component seemed to have some structure, but it was not resolved. At 1500 gauss three components were observed on a faint background, the middle one being the brightest of all. A similar structure with a slightly different spacing was also seen at 2100 gauss. As the field increased in strength, the middle component shifted slightly toward the short wave length side, and two lines appeared on the violet side of it when the field reached 2500 gauss. This stage is seen in Fig. 5, PL. II. It is very curious that the spacing of these three lines are almost the same

FIG. 6.

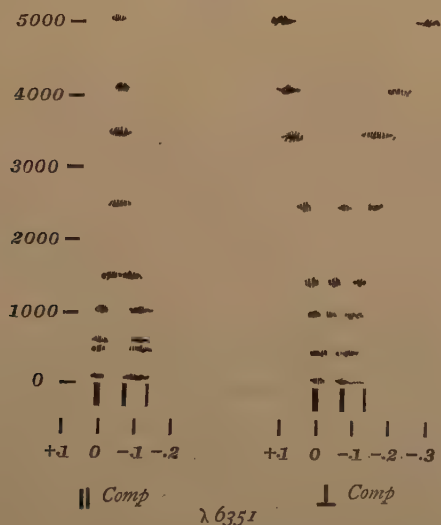


as those of the original line. A further increase of the field detached this group of lines from the remaining, and two groups were distinctly observed at 2700 gauss, the group on the red side consisting of an apparently structureless broad band. They separated as the field was raised, and a diffuse doublet was observed at strong fields. The behaviour of the components of this line is illustrated in Fig. 6.

$\lambda 6351$ (Fig. 7. PL. III)

This line consists of three components at 0.000, -0.069 and -0.143, and their behaviour was studied in fields up to 5000 gauss. The parallel component of this line was so sensitive that a field of only 70 gauss modified enormously their appearance, i.e., the main line became broad, and hazy, and two satellites approached together showing the appearance of one diffuse line. At the field of 500 gauss their fusing seemed to have been completed, and only two lines, in consequence, were observed on some background. As the field was increased, the component formed by the fusion of the two satellites got sharper, and at the same time displaced gradually toward the main line, which also, affected by the other component, shifted toward the approaching one. A single broad line was then observed at the field of 1500 gauss. Further increase of the field made this line narrower, and at fields above 3000 gauss a very fine line was obtained at a position slightly displaced toward the short wave length side of the main line.

FIG. 8.



The perpendicular component of this line was also very sensitive to the action of the field. The photograph taken at the field of 75 gauss showed an appearance very much modified in comparison with

the one at the zero field. At 500 gauss a hazy line nearly in coincidence with the main line and a broad line having some structure occupying the positions of the satellites were seen. As the field was raised, the fusion of components took place and a thick bright line was observed in the middle of the back ground at the field of 1200 gauss. Further increase of the field made the central line sharper and stronger, and produced also one line on the each side of it, thus giving an appearance of a triplet with a faint background. This stage is seen in Fig. 7. The outer component on the short wave length side then fused with the middle one. The line thus formed displaced from the other forming an unsymmetrical doublet. Such was observed above the field of 4000 gauss.

Thus, on the whole, the positive branch of the perpendicular component of the main line suffered the normal amount of separation, while the negative one, fusing with a satellite in a weak field, gave a strongly deviated branch at high fields. The plates taken at fields below 1000 gauss were difficult of interpretation, but it may be noted that the fusion of components took place simultaneously in both components of the polarization, and that a bending of the branch occurred as the result of such fusion. The behaviour of the components of this line is represented in Fig. 8.

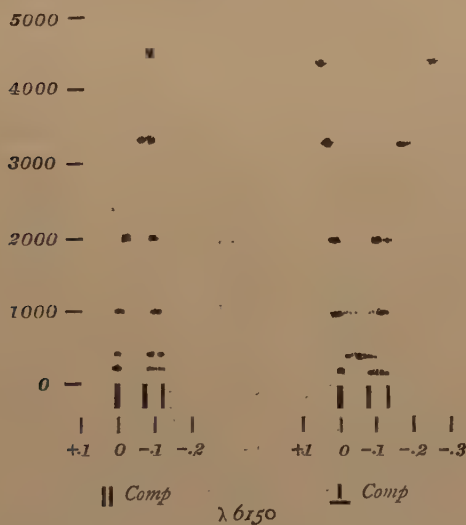
λ 6150 (Fig. 9. PL. III)

This line has three components at 0.000, -0.068 and -0.126. As with the other complex lines, the satellites were very sensitive to the action of the field. In the parallel component the main line showed a distinct broadening, but its centre remained almost in its initial position until the field strength reached to about 1000 gauss. The satellites on the other hand approached one another under weak fields and formed a rather broad line with a wave length intermediate between them. Such a stage was seen even at the field of 180 gauss. With an increasing field this line got finer, and two lines of nearly equal intensity and sharpness were observed at 1000 gauss. From this stage they began to approach each other forming a broad line first, which then became narrower as the field was gradually raised. At the field of 3300 gauss, only a fine single line as the result of fusion was observed nearly in coincidence with the middle component of the original line. Thus the behaviour of this line in the parallel

component was similar to that of $\lambda 6351$, and the same will be observed in the other component.

Now, in the case of the perpendicular component the plates taken in weak fields were difficult to interpret. But the main line seems to have decomposed into two owing to the field, the negative component of which fused with approaching satellites forming a strongly deviated branch in strong magnetic fields. Here we observed that the fusion of approaching components took place simultaneously in the parallel and the perpendicular components. A diffuse doublet was obtained at a field higher than 3000 gauss, while a single line was seen in the parallel component. The whole course of the changes followed by the components of the line is shown in Fig. 10.

FIG. 10.



The common feature of the effect observed in the four complex lines of bromine described above may be summarized as follows:

Complex lines having similar structures are not all affected in a similar manner by the magnetic field. Satellites are very sensitive to the action of the field. In weak fields, they fuse together in the parallel component and the line thus formed unites again with a main line as the field is increased. The appearance of this line was very sharp in $\lambda 6150$ and 6351 , but not in the others.

In the perpendicular component, the behaviour of the satellites

were difficult to follow in weak fields, but two broad components were always obtained in strong fields.

The Zeeman Effect of Single Lines of Bromine

The Zeeman effect on single lines was studied with the arrangement having the echelon and the prism combination. In this case, the lines are too crowded to photograph both polarized components one above the other, so that a nicol prism was substituted in place of the Iceland Spar and the rotating plate; thus one polarized component only was recorded on one plate without reference lines. On such plates, the numbers of magnetic components and their separations could only be determined. Two of the photographs taken thus are shown in Figs. 11 and 12. The lines recorded are those lying between λ 5600 and λ 4600, and strong lines only were measured. It is worth while to notice that the measurable lines showed magnetic triplets, the distances between the outer components are, however, wider than that of the normal triplet.

The results of the measurement are given in the form of a table. Here $\Delta\lambda$ represents the distance of the outer components of magnetic triplets, and the numbers in the second column give the mean

λ	$\frac{\Delta\lambda}{H}$	$\frac{\Delta\lambda}{H\lambda^2}$	$\frac{\Delta\lambda}{\lambda^2 H} / 0.94 \times 10^{-4}$
4623	3.02×10^{-13}	1.41×10^{-4}	$3/2$
4679	2.88 "	1.32 "	$7/5$
4720	2.80 "	1.25 "	$4/3$
4743	2.54 "	1.13 "	$6/5$
4767	3.77 "	1.66 "	$(7/4)$
5165	5.62 "	2.11 "	$9/4$
5182	4.00 "	1.49 "	$8/5$
5238	5.21 "	1.90 "	$2/1$
5304	4.00 "	1.42 "	$3/2$
5332	3.73 "	1.32 "	$7/5$
5590	4.25 "	1.36 "	$(13/9)$

of the ratio of the magnetic separation to the fields corresponding to 2100, 2700, 3030, 3550 and 4150 gauss. 0.94×10^{-4} in the fourth column is the value $\frac{\Delta\lambda}{\lambda^2 H}$ for the normal triplet, so that the last column gives approximate values of the ratio of specific separation of the lines in the first column to that of the normal triplet.

Summary

1. The structures of lines in the bromine spectrum were examined with a 40-plate echelon grating.

2. More than a dozen lines were found to have complex structures, and they belong to the lines of the arc type.
3. The influence of magnetic field upon the complex lines $\lambda\lambda 6632, 6560, 6351$, and 6150 was studied. It was found that these lines, though they have similar structures, were not affected in a similar manner. In all cases satellites were very sensitive to the action of the field. In a strong magnetic field, they always gave triplets.
4. The Zeeman effect on a number of single lines was also studied; they all showed magnetic triplets with wider specific separation.

In conclusion, the writer wishes to express his thanks to Prof. T. Mizuno for the interest he has taken in this work.



Br. spectrum
photographed with
Echelon-Prism
Combination.

Fig. 1

$\frac{1}{H}$ Comp.
 $H=3030$

Fig. 11

$\frac{1}{H}$ Comp.
 $H=3800$

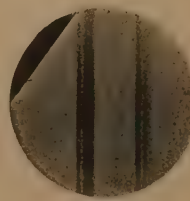
Fig. 12



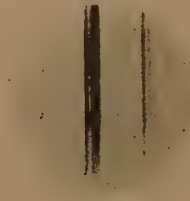
$\lambda 6632$



$\lambda 6560$



$\lambda 6351$



$\lambda 6150$

Fig. 2

$\lambda 6632$

|| Comp.

⊥ Comp.

Field
Strengths

520

1040

2840

4300

5800

8600

10000

$\lambda 6560$

|| Comp.

⊥ Comp.

Field
Strengths

240

700

2100

2400

2700

3500

4800

Fig. 4

Magnification: 10.

Fig. 5



Fig. 9

Magnification: 10.



Fig. 7

On the Distribution of Charged Ions in the Path of an Electric Discharge through a Tube Containing Bromine Vapour

By

Masamichi Kimura

(Received Oct. 20, 1919).

The determination of the electric conditions of vapours and gases in discharge tubes is highly interesting. The distribution of electric intensities along the path of the discharge was already studied by many investigators. H. A. Wilson¹ examined numbers of ions along the path of discharges, but nothing was, so far, known as to the distribution of singly and multiply charged ions separately. Such distribution may be examined indirectly by using a spectroscopic method, and some result thus obtained is given in the following pages.

According to Stark, the emission centres of spectral lines of spark type are doubly or triply charged atomions of elements, and lines of arc type are emitted by atomions which have lost one electron. If we adhere to this view, we can easily determine by using a spectroscope the distribution of charged ions along the path of an electric discharge.

In a preceding paper, the lines of spark and of arc types of bromine are described, and using these data, we will consider the charged states of bromine ions in various parts of a discharge tube containing that vapour.

¹ Phil. Mag. [5], xlix. 505, (1900).

Let us first take the case in which the vapour pressure of bromine is sufficiently low. Starting from the salt cathode, we had streams of cathode rays, the path of which looked pale white. Its spectrum consisted chiefly of lines at $\lambda\lambda$ 578, 524, 533 and a certain number of lines in the blue-violet region, which belong to the lines of the spark type. This shows that bromine atoms are ionized by the impact of cathode rays to the state of doubly or triply charged atomions.

If the diameter of the tube was about a centimeter, the positive column was filled up uniformly with a glow of chamois yellow colour. Its spectrum consisted of a fluted band extending from green to red, and some lines of the pink spectrum of this element. The relative intensities of the band and the line spectra varied with the diameter of the tube; when the tube got wider, the band spectrum was brought up at the expense of the other. The lines of the pink spectrum are chiefly those of the arc type, and this indicates that there are plenty of bromine atomions which have lost a single electron; beside these, there were emission centres of the band spectrum. If we take the view that band spectra are emitted by certain vibrations in molecules, the existence of such a band spectrum seems to suggest that a part of the bromine molecules, when bombarded by electrons, would not be split up into atomions, but vibrations would be called forth in the valency electrons within to make them emit the band spectrum. This explanation seems to be supported by the fact that a weak excitation is favorable for the emission of such a band.

Now, if a constriction was made in a part of the discharge tube, the electric states of bromine in that part would be modified. The current density and the potential gradient would be increased, and a greater energy would be absorbed there. Consequently the process of ionization would proceed deeper inside the atom, and a number of multiply charged atoms would be formed when the energy absorbed by a single molecule exceeded a certain amount. In fact, such a constriction caused the colour of the glow to change to bluish green, the spectrum of which consisted chiefly of lines of the spark type, indicating that atomions which had lost two or more electrons had been produced.

It was sometimes observed that some parts of the surfaces of silver bromide electrodes emitted the green light due to silver. This

seems to indicate that, when the discharge was sufficiently strong to remove valency electrons out of surface molecules, positive atomions of silver would have been formed, so that silver would emit its characteristic light.

Next, when the vapour pressure was not low, and the discharge tube had also no constriction, the colour of the glow in the positive column was pink. Its spectrum was made up mainly of lines of the arc type, indicating that the greater majority of the ions produced there were singly charged atomions.

An introduction of a constricted portion in the path of the discharge gave rise to some spark lines, but this was not sufficient to suppress four lines characteristic of the arc type. In other words, if the vapour pressure of bromine was not low enough, the greater part of singly charged atomions remained in that state, even when the ionizing energy was augmented. However, when a spark gap was inserted in the discharge circuit, greater energy would be spent in a single discharge. The process of ionization would consequently proceed further, and some atoms would have been ionized into the state of multiply charged atomions. In the actual experiment this was indicated by the change in the colour of the glow.

The writer's sincere thanks are due to Prof. T. Mizuno for the interest he has taken in this work.

Studies of the Spectrum of Chlorine I

Emission and Absorption Spectra

By

Masamichi Kimura and Mitsuharu Fukuda

(Received Oct. 20, 1919)

The band emission spectrum of chlorine is not yet thoroughly studied, and its relation to the absorption spectrum of that vapour seems to be quite unknown. In the case of iodine, one of the present writers in collaboration with Prof. R. W. Wood¹ found that the emission and absorption spectra of iodine are not complementary, though every emission line of the band has an absorption line in coincidence with it, but there are many absorption lines which are not represented in the emission spectrum of iodine.

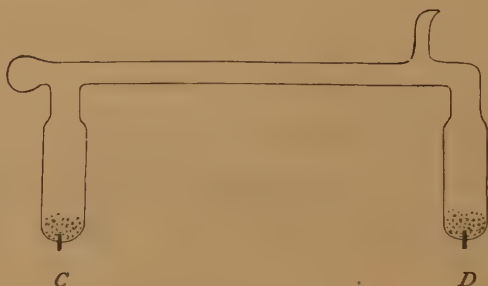
It is the object of the present experiment to see whether a similar result holds true in the case of chlorine, and the result thus far obtained will be described below. The emission band will be first described and it will then be compared with the absorption spectrum.

In the preliminary part of the work we had considerable difficulty in getting a good tube emitting bright light in the band spectrum, and we found that tubes having sodium chloride electrodes work fairly well. The form of tube used is shown Fig. 1. A certain quantity of welldried pure sodium chloride was put in the side tubes *C* and *D* just enough to cover the platinum wires sealed at the ends and these were connected by a piece of tubing of about 5 mm. diameter,

¹ *Astrophys. J.* **46**, 181 (1917).

and 20 cm. in length, one end of which was blown out into a fine bulb. The tube thus prepared was connected to a pump and a heavy discharge was sent through during the evacuation. When the tube was sealed off from the pump the carbon monoxide band soon appeared which superposed upon the band spec-

FIG. 1.



trum of chlorine, so that to get rid of the monoxide the tube was connected to the pump during the exposure to a spectrograph. The image of an end-on emission from the tube was projected on the slit of a spectrograph having a good Hilger replica grating and the spectrum was photographed with an achromatic objective of 55 cm. focus. An exposure of one hour was sufficient to secure a good negative on a Wratten panchromatic plate, the linear dispersion on the plate in the first order spectrum being about 0.033 mm. per 1 Å at $\lambda 4900$ and 0.031 mm. at $\lambda 4200$.

One of the plates thus obtained is reproduced in Fig. 2. with wave lengths for certain lines. Here lines in the line spectrum of chlorine are superposed on the back ground of the band spectrum extending from red to violet. The spectrograph employed was, of course, not powerful enough to resolve individual lines belonging to the band spectrum, but the general features could be seen with it.

The relative intensities of the line and the band spectra emitted by such a tube depended upon the diameter of the tube and the current density, and the greater the diameter and the smaller the current density, the stronger was the band in comparison with the line spectrum. Several photographs were taken with tubes having sodium chloride, potassium chloride and bismuth trichloride, as electrodes, and the same band was always obtained with these salts. Thus it is clear that the band recorded here is due to chlorine.

The brightest part of this band lies between $\lambda 5100$ and $\lambda 4800$, but a weaker portion of it extends farther up to $\lambda 6500$ on the red side and down to about $\lambda 3800$ or more on the violet side. With the

dispersion used the spectrum presents an irregular fluted appearance, but it did not appear to have heads.

The emission band described above is now to be compared with the absorption spectrum of chlorine. The latter was investigated minutely by Laird¹, who found that the spectrum consists of a line absorption extending from blue to yellow and a very broad general absorption in the violet region. The line absorption spectrum of one meter of chlorine at one atmospheric pressure begins at about $\lambda 4800$ and extends up to $\lambda 5350$, while the general absorption starts nearly at $\lambda 4700$. This limit proceeded toward the red side as the length of the chlorine tube was increased.

If we compare these results with that obtained in our case of the emission band of chlorine, we see that the emission band is strongest at the region where the general absorption of the gas is so. In order to ascertain this the absorption spectrum was photographed with the same instrument. The gas was chemically prepared in the ordinary way and after being well dried, it was filled at one atmospheric pressure in a piece of glass tubing of about two meters long. A crater of a carbon arc was projected through the gas on the slit of the spectrograph, and after an exposure of a few minutes the slit was illuminated by the light from a chlorine tube to give a comparison spectrum.

An enlarged photograph thus obtained is reproduced in Fig. 3. Lines of the absorption spectrum were barely resolved on the original negative especially in the region from $\lambda 5100$ to $\lambda 5200$, while the emission band in the same region showed only a fluted appearance. This fluting did not coincide exactly with that of the absorption spectrum. Moreover, the structure of the emission band seems to be more complex than that of the absorption band.

It will be further observed that the emission band begins to become intense as the region is approached where the absorption get strong, and that in the part of the spectrum from yellow to red where the gas is very transparent, the band emission is very faint, while the gas is very opaque in the region blue to violet, but the emission is very strong there.

Thus it may generally be concluded that chlorine, when excited electrically, emits light strongly in the band spectrum in the region where the gas absorbs light most intensely.

¹ *Astrophys. J.* 14, 85 (1901).

In the near future the authors wish to resume the investigation with an instrument having a higher resolving power sufficient to resolve the lines in the emission band of chlorine.

Summary

1. The emission and absorption band spectra of chlorine vapour were studied with a grating spectrograph having a moderate dispersion.
2. It was found that they are not exactly complementary, but chlorine emits light strongly in the region where the vapour absorbs light most intensely.

The writers' sincere thanks are due to Prof. T. Mizuno for the interest he has taken in this work.

Studies of the Spectrum of Chlorine II The Influence of Magnetic Fields upon Spectral Lines of Chlorine

By

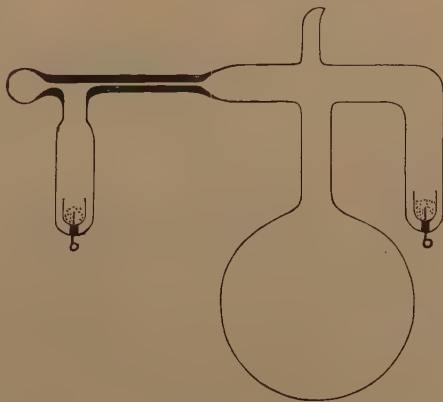
Masamichi Kimura and Mitsuharu Fukuda

(Received Oct. 20, 1919)

The spectrum of chlorine, like the other elements of the halogen group, has not yet been studied under a high resolving power. Berndt¹ tried to investigate the Zeeman effect on lines of this element, but no result was obtained. One of the difficulties met with in the spectroscopic study of this element is the preparation of chlorine tubes giving bright light. Various forms of tube having both internal and external electrodes were tried, but all were unsatisfactory until we finally adopted tubes provided with salt electrodes. These tubes were of the form shown in Fig. 4.

The capillary was drawn down from a 6 mm. tubing, one end of which was blown out into a fine bulb, the length of the capillary part being about two cms. in length. This was jointed with two side tubes having a small quantity of a well-dried salt and a big bulb, intended to increase the whole volume of the tube and thereby reduce changes of the gas pressure brought out by the discharge. Among the salts tried, sodium chloride gave the best result. During the evacuation of the tube,

FIG. 4.



¹ Ann. d. Phys. 8, 625 (1902).

heavy discharges should be sent through and the wall of the tube was also highly heated. Even with such treatment the band due to carbon monoxide appeared, soon after the tubes were sealed off, in wider parts, but it did not appear in the capillary part.

The colour of the light emitted from the capillary part was bright bluish green, consisting of the lines of chlorine, while the glow in the wider part was pale white, the spectrum of which was a mixture of the line and the band spectra of this element. The end-on emission from the capillary part was examined with the forty plate echelon grating described on the preceding paper.

Certain lines were found to be complex, and their structures and behaviour in magnetic fields were studied, but the results will be discussed in another paper. In the following pages magnetic separations of single lines will be described.

The short capillary part of the chlorine tube was horizontally mounted between truncated pole pieces of an electro-magnet of the Du-Bois type, and this was observed in the direction perpendicular to the lines of force. As a polarizing apparatus a Nicol prism was used. The polarized image of the end-on emission was formed on the echelon slit by means of a photographic objective of Zeiss Tessar. The light, then analysed by the echelon grating and the direct vision prism, was photographed with the objective of one meter focus. The dispersion of the echelon was horizontal, while that of the prism vertical, so that the spectrum thus made showed an appearance of a vertical column of light made up of short lines. (Fig. 5)

The light was so bright that half an hour's exposure gave a good negative on a Wratten panchromatic plate when the field was not excited, and the Nicol prism was out, strong lines in the region blue to green being, of course, over-exposed. The field strength was determined by the aid of a bismuth spiral.

The magnetic separation of all the single lines recorded on the photographic plates was of triplet type, the middle components being polarized in the direction of the magnetic field. The amount of separation of the outer components, however, varied from line to line (Figs. 6 and 7). Photographs were taken at various fields varying from 2000 to 6000 gauss. At high fields, the magnetic components were too diffuse to admit of exact measurements, so that the three plates taken at the fields of 2700, 4100 and 4800 gauss were selected to determine the amount of separation. Fifteen lines were measured,

but some of them were ambiguous, so that they are not given in this paper.

The results obtained are given in the form of a table; the first column gives the wave lengths of the lines measured, the second, the third and the fourth, the values of $\frac{\Delta\lambda}{\lambda^2H}$ for three different fields, and the fifth the mean values of them, $\Delta\lambda$ in the above expression representing the distance of outer components of magnetic triplets, and H denoting the field strength. In the last column ratios of the specific separations of the lines to that of the normal triplet, i.e., $\frac{\Delta\lambda}{\lambda^2H} / 0.94 \times 10^{-4}$ are given.

Thus it will be observed that the amounts of the magnetic separation of these lines are proportional to the strength of the field and that they stand in simple relations to the amount of separation in the case of the normal triplet.

λ	$\frac{\Delta\lambda}{\lambda^2H} \times 10^4$			Mean Values of $\Delta\lambda/\lambda^2H \cdot 10^4$	$\frac{\Delta\lambda}{\lambda^2H} / 0.94 \times 10^{-4}$
	$H=2700$	$H=4100$	$H=4800$		
4781	1.26	1.26	1.25	1.26	$\frac{4}{3}$
4786	.94	—	—	—	1
4794	1.49	1.48	1.50	1.49	$\frac{8}{5}$
4896	—	1.25	1.28	1.27	$\frac{4}{3}$
4904	1.05	1.04	—	1.05	$\frac{10}{9}$
5078	1.43	1.42	1.41	1.42	$\frac{3}{2}$
5218	1.39	1.41	1.39	1.40	$\frac{3}{2}$
5221	1.90	1.85	1.85	1.87	$\frac{2}{1}$
5392	1.10	1.08	1.10	1.09	$\frac{7}{6}$

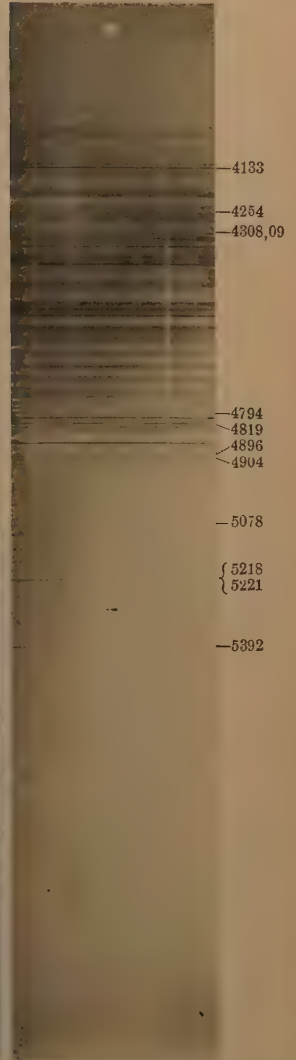
Summary

1. The Zeeman effect on certain single lines in the spectrum of chlorine was studied.

2. All these lines except λ_{4786} were found to give magnetic triplets of wider specific separations than that of a normal triplet, but they bear simple relations to that of a normal triplet.

The writers' sincere thanks are due to Prof. T. Mizuno for the interest he has taken in this work.

Emission Band
Spectrum



Absorption Band
Spectrum



H=O

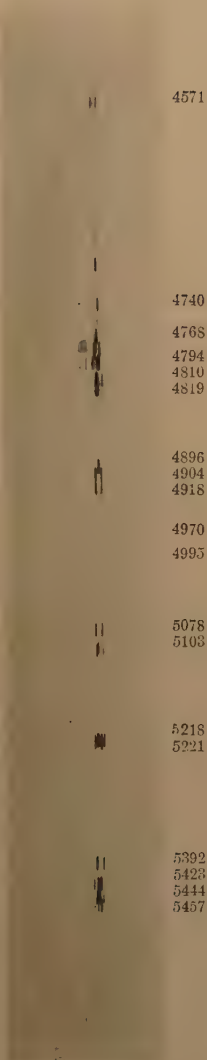


Fig. 5
Magnification: 1.5

H=2700
L Comp.



Fig. 6
Magnification: 2

H=4800
L Comp.

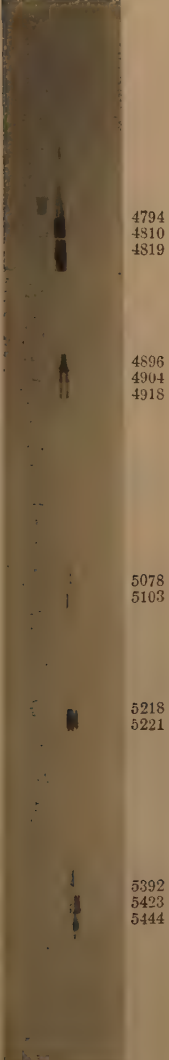


Fig. 7
Magnification: 2

Unilateral Conductivity of Tubes having a Salt Electrode

By

Masamichi Kimura and Jun-ichiro Nagahata

(Received Oct. 20, 1919)

One of us, while studying the spectrum of chlorine, found that a tube having sodium chloride as one electrode allows to pass an electric current easily in one direction, but not in the other. This unilateral conductivity possessed by such a tube seemed to be worthy of study, and the condition of the tube for the perfect rectification was examined, and some of the results obtained will be described below.

The tube used in this study was a half litre bulb provided with two side tubes having platinum electrodes, and a well dried sodium chloride was put in one of the side tubes just enough to cover the top of the platinum wire. Such a tube was connected to a pump, and residual air, with gases evolved by heating the wall of the tube and also evolved by discharges, was pumped out. As exhaustion proceeded, the discharge from an induction coil began to get difficult to pass when the platinum electrode was cathode. But when the salt electrode was made cathode current passed very easily, showing that the tube exhibits an unilateral conductivity.

In order to see the mode of rectification of a high tension alternating current by such a tube, the method of a glow oscilloscope and a falling plate camera was adopted. A tube thus prepared was connected in series with the oscilloscope in the secondary circuit of a Bilitzen transformer of $\frac{1}{4}$ K. W. giving about 6000 volts, and the lengths of the glow along the wire electrodes of the oscilloscope were

photographed by a falling plate camera. Photographs thus obtained are shown in the annexed figures. Fig. 1, represents the form of the alternating current itself given by the transformer, and Fig. 2 shows

FIG. 1.



FIG. 2.



the current form rectified by the tube. This shows clearly that the tube allows current in one direction but hinders it in the other.

If the quantity of the salt at the electrode was increased the rectifying property of the tube began to be affected, and when it exceeded a certain amount, the tube showed a tendency to lose the unilateral property, provided the other electrode had a small surface.

Thus the quantity of the salt at the electrode seems to play an important rôle in the process of rectification, the proper amount of the salt being such that it just covers the platinum wire.

The salt electrode, when rectifying the current, got very hot, and the tube allowed the current only from the colder electrode to the hotter one. In this respect the salt electrode seems to behave like a Wehnelt cathode. The salt electrode and the glass wall surrounding it were coloured, exhibiting a beautiful violet tint. This would be due to the sodium which had been decomposed by the discharge from the salt electrode; in fact, the above colour resembles that of the colloidal solution of sodium in alcohol. The chlorine set

free in consequence of the decomposition of the salt would diffuse out into the tube.

The mode of the unilateral conductivity possessed by the tubes may be explained in the following way. An electric current in such a tube would chiefly be carried by positive and negative ions, but very scantily by free electrons. For the latter have a very strong affinity toward chlorine and would soon unite with it to form negative ions of chlorine, so that the free electrons left in the tube would be very few.

If the salt electrode was made anode, negative ions of chlorine would proceed to the salt electrode, where they would unite with free sodium, forming sodium chloride. By this process the free chlorine ions in the tube would be cleared away and the vacuum would improve, the discharge becoming thereby difficult. But if the salt were made cathode, the chlorine ions would proceed toward the other electrode and the greater part of them would unite with the electrode and disappear from the tube. On the other hand, the salt molecules at the cathode would be bombarded by the coming positive ions of residual gases and consequently would be decomposed into sodium and chlorine atoms. Beside this, plenty of electrons would have been liberated at the hot sodium lying in the neighborhood of the electrode just as in the case of a Wehnelt cathode. The chlorine thus set free would soon catch electrons, and become negative ions, so that the supply of chlorine would continue so long as the process was going on, and the current would thus flow.

The unilateral conductivity was not only limited to the electrode of sodium chloride, but potassium chloride, barium chloride etc. behaved in a similar way, the explanation given above being perhaps equally applicable.

Summary

1. Vacuum tubes having a salt electrode were found to have the property of rectifying high tension alternating currents, and the conditions of perfect rectification were examined.
2. An explanation of the process of rectification was afforded.

The writers' cordial thanks are due to Prof. T. Mizuno for the interest he has taken in this work.

A Short Note on the Arc and Spark Lines of Iodine

By

Masamichi Kimura

(Received Oct. 20, 1919)

Iodine emits light in many different ways. When it is excited electrically the colour of the light varies with the modes of excitation and it also changes with the forms of discharge tubes. The changes thus called forth in its spectrum were studied and the result obtained is given in the present note.

The colour of the glow in an ordinary Geissler tube containing iodine appears yellow in the wide part, but bluish green in its capillary. When a part of this capillary was further made narrower, the light from this part became more bluish, indicating that a change had occurred in its spectrum. In order to study the change brought out in the spectrum, a conical capillary was used in place of an ordinary one. Such a capillary was drawn from an ordinary glass tubing of 5 mm. diameter, the narrowest part being about 0.1 mm, and its length 10 mm. A well defined vertical image of the glow in this conical part was formed on a slit of a small prism spectroscope, and the light coming from various points on the axis of the cone of light were simultaneously studied. An enlarged reproduction of the spectrogram thus obtained is given in Fig. 1, the upper part in the photograph representing the spectrum of the light emitted from the narrowest part of the capillary.

It was observed that certain strong lines in the upper part disappeared entirely from the lower, while a number of faint lines in the

upper were enhanced in the lower half. Thus lines in the iodine spectrum may be divided into two types, the strong lines belonging to the first type being, $\lambda\lambda$ 5178, 5185, 5199, 5216, 5678, 5690, 5710, 5739, 5950, 6075 etc., and those of the second, $\lambda\lambda$ 4862, 4897, 4917, 5119, 5235, 5894 etc.

From these we see that lines of the first type belong to the spark lines of iodine, while those of the second type to the arc lines. Thus the insertion of a constricted part in the path of the discharge makes spark lines stronger and suppresses arc lines.

Such a change of the intensity distribution in the spectrum was also brought out by sending condensed discharges through an iodine tube having no constricted portion. When such a tube was connected to the terminals of an induction coil and simply excited by it, the spectrum of the light consisted chiefly of lines of the arc type and of bands, lines of the spark type appearing, however, as faint lines at $\lambda\lambda$ 476, 516, 534, 540 and 550 (Fig. 2). But when a small condenser and a spark gap were put in the circuit, the arc lines and the band spectrum in the region from green to red, were reduced in intensity, and the spark lines enhanced at the same time.

When the gap was widened, the spark lines in the region from blue to violet were enhanced at the expense of those lying in the other region. In other words, the region of the maximum intensity in the line spectrum of iodine displaced toward the short wave length side as discharges got heavy. This change is seen from the photographs shown in Figs. 3 and 4.

Summary

1. The effect of constricting a portion of a discharge circuit on the spectrum of the light emitted from that part was examined and it was ascertained that spark lines were enhanced there while arc lines were suppressed.

2. The influence of a condensed discharge upon the spectrum of iodine was studied and it was found that the position of the maximum intensity in the spectrum of iodine displaced toward the short wave-length side as the discharge got heavy.

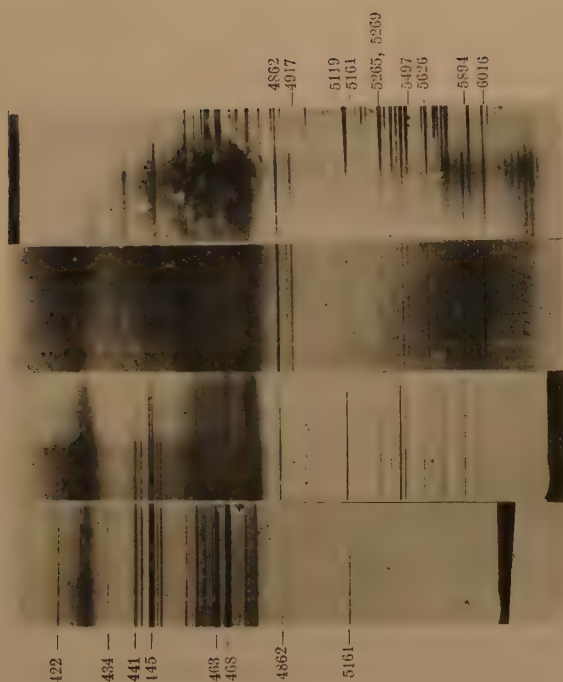
In conclusion, the writer wishes to express his thanks to Prof. T. Mizuno for the interest he has taken in this work.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.



Capillary

Bulb

Small spark gap

Medium spark gap

Largest spark gap



Electrical States of Iodine Vapour when emitting Line and Band Spectra

By

Komataro Makino

(Received Oct. 20, 1919)

When a Geissler tube containing iodine vapour is excited by an induction coil, the light emitted from the capillary part is chiefly of the line spectrum, while band spectra appear in a wide part of the tube. The object of the present experiment is to examine under what electric conditions of iodine vapour the line and band spectra will be emitted.

A single discharge due to a break of the primary of an induction coil consists really of a few partial ones. Now, when an iodine tube was excited by the coil, the colour of the glow corresponding to each partial discharge was found the same when examined with a rotating mirror. But when the tube was excited by a transformer, a single discharge in one direction consisted of many partial ones having different colours characteristic of the line and band spectra. The current strength in this case corresponding to these partial discharges was compared by means of an oscilloscope and a falling-plate camera.

When an oscilloscope was put in a circuit containing an iodine tube, the glow along the wire electrodes in the oscilloscope became too faint to give a good impression of the partial discharges on the falling photographic plate. Therefore a pair of plate electrodes having 1 cm. width were used instead of the ordinary wire electrodes and the glow was observed edgewise to increase the brightness. Such a tube was put in series with an iodine tube in a circuit containing a self-

induction and an adjustable capacity, and excited by a transformer giving about 5000 volts.

The arrangement of the tubes and optical system are shown in Fig. 1. *A* represents the oscilloscope, *B* an iodine tube and *SS* the slit of a falling plate camera, on which the images of both glows were formed lying side by side by means of a system of lenses *L*. As iodine tube, a fine capillary was dispensed with, and a piece of tubing of about 4 mm. internal diameter was used; and the condenser was so adjusted that the partial discharges through the iodine tube would emit the line and band spectra. Observations were preliminarily done with a rotating mirror on the colours of the glow of partial discharges in the iodine tube and the corresponding lengths of the glow in the oscilloscope.

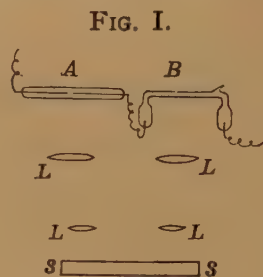


FIG. 1.

Now, in the case of discharges giving light in the line spectrum, the glow in the iodine tube was concentrated into the form of bluish green threads, but when the light was emitted in the band spectrum the whole section of the tube was filled up with a glow of a chamois yellow colour. Thus line discharges appeared as strong sharp lines on the photographic plates, while band discharges as rather faint broad bands. Owing to this difference it was easy to compare instantaneous currents corresponding to the glows emitting the line and band spectra. One of the photographs thus taken is shown in

FIG. 2.

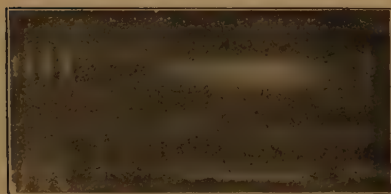


Fig. 2 and it was observed that the current in a partial glow giving the line spectrum is about three times that of the band discharge.

Next, it is desirable to know the potential gradients along the discharges corresponding to such partial ones, but we had no simple means of determining them. But when the iodine tube was excited by an induction coil, a discharge consisted of a few partial ones having all the same colour, the line spectrum appearing in a condensed discharge, while the band in a weak one. Thus, when a pair of fine platinum wires were inserted in the discharge tube and mean deflections of an electrometer, the terminals of which were connected to

platinum wires, were determined, corresponding to both weak and heavy discharges, they might be taken as a rough measure of potential gradients in the glows in the line and band discharges. The values thus found were 32 v/cm, 46 v/cm and 64 v/cm in the cases of the discharges emitting the light in the spectra as shown in Figs. 2, 3, and 4 in the preceding paper.

If we consider these results together with the results obtained by the oscilloscope experiments, it is seen that in the case of iodine the energy required to emit spark lines is about five or six times that of the band spectrum.

Summary

1. By employing a glow oscilloscope instantaneous current strengths in partial discharges emitting the line and band spectra of iodine were compared.

2. Potential gradients in the path of discharges emitting the line and band spectra were roughly determined.

The writer's sincere thanks are due to Prof. M. Kimura for his kind guidance.

Figures produced by Crystallization of Potassium-bichromate

By

Masamichi Kimura

(Received Oct. 20, 1919)

The crystallization of potassium bichromate on gelatin film is of special interest. It gives patterns of crystals very much resembling seaweed. A short account of the mode of the formation of crystal figures and some consideration about them will be given below.

A small quantity of a saturated solution of potassium bichromate was put on a clean glass plate and let it be evaporated. A number of crystals appeared, as water evaporated, first along the boundary of the solution. They grew inward building up bigger and regular pieces of the crystal. During this process, another growth sometimes also took place outward at certain points of the boundary. The mode of the outward growth of crystals was quite different from that of the inward one, and the whole form somewhat resembled branches of coral. When water evaporated further, and the solution was super-saturated, another form suddenly took place in the central part presenting figures resembling seaweed. The formation of such crystal figures was very rapid and it was difficult to follow the process with the naked eye.

We have thus three different modes of the growth of potassium bichromate crystals and they are shown in Fig. 1, where 1, 2 and 3 represent first, second and third forms of the crystal growth respectively.

The form first mentioned is simple; its growth would be, of course, due to successive additions of molecules in a regular way on

the surface of crystals already formed. The second is built up of a number of small fragments of the crystal lying side by side in a very irregular manner. This mode of growth may be explained in the following way. Suppose that a number of crystals were first formed along the boundary of the solution. The surfaces of these crystals facing outward would be coated with a thin layer of the saturated solution, and evaporation would make the solution more concentrated. Consequently, small pieces of crystals would be formed, and they would come into contact with bigger ones by the action of gravity or



FIG. 1.



FIG. 2.

by capillarity. Then capillary action would come into play and the surfaces of freshly deposited crystals would once more be coated with the solution. These processes would be repeated until no solution was further sucked up.

Next, the third form looks something like seaweed. A microscopic observation has revealed its mode of formation. The form appeared suddenly at the end of the crystallization of the whole liquid. When we looked through a microscope at the central part of the portion covered by the solution, sudden births of small pieces of the crystal were observed here and there. From these pieces, crys-

Successive stages of formation of crystal trees of potassium bichromate on gelatin film.



FIG. 3.

1. initial.	2. after 4 mins.	3. after 7 mins.
4. after 12 mins.	5. " 15 "	6. " 17 "

tallization started very rapidly along many different paths, branching at various points forming figures as illustrated in Fig. 1.

A high speed of growth was characteristic of the formation of these crystal trees, and this is due to the fact that the solution in this case was in a state of supersaturation. The mode of growth may be explained in the following way: The study of crystal structures with X-rays showed that atoms in a crystal arrange themselves in a regular way, and that parts which correspond to anion and cation as a whole lie side by side. This seems to suggest that the force holding these atoms or groups of atoms together is of electric nature. If



FIG. 4.



FIG. 5.

this view is correct, it may be considered that an electric field will leak out from the surface atoms in the boundary of the crystal.

Thus when a crystal is put in water, the atoms on its surface will be in the vicinity of atoms in water molecules, and if the attraction between the atoms themselves in the crystal is smaller than that between the atoms of water and crystal, the latter will begin to dissolve. In the case of an electrolyte it may happen that one cation and two anions, for example, may go into water, but one of the anions has no partner, so that it can not be in a stable condition. Such anion will easily be taken up by the surrounding water mole-

cules, and it will remain as an anion or find a partner to form a molecule.

Now, when water evaporates from such a solution described above, it becomes concentrated, and this will reduce the degree of ionization in the solution, a number of pairs of ions being united into molecules. This union will not, however, be complete, and an intermolecular field will leak out of molecules, which will therefore behave like electric doublets. In virtue of this stray field, some of these molecules will again combine forming a molecular aggregate having an electric polarity. The formation of such aggregates may be considered as a preliminary process of crystallization. Thus, in a saturated solution there will be a number of such molecular aggregates and when the solution attains the state of supersaturation, a great majority of solute molecules will take the form of complex molecular aggregates. When such molecular aggregates happen to be within the spheres of action of the others, they come into contact, and their equilibrium distribution will be disturbed. Some other aggregates lying in their neighborhood will be attracted into the field and consequently a new larger aggregate



FIG. 6.

will be formed.

Thus the deposit of solute out of the solution takes place very rapidly, and this process will continue until the excess of the solute gets out of the solution. The paths traced out by the glowing crystal may roughly be considered as an indication of the distribution of such aggregates in a supersaturated solution just before the crystallization has taken place.

When the solution was poured on a gelatin film instead of a glass plate, figures traced out by the growth of the crystal were only of the third form mentioned above. In this case, the solution was absorbed by the gelatin which would prevent quick diffusion of molecules and their aggregates, and consequently the crystallization would not start until the solution reached the stage of supersaturation. The speed of the crystal growth was thus reduced and successive stages of the growth were easily examined. Some of them are shown in Figs. 2, 3 and 4.

It is observed that crystal trees have many branches like seaweed. This branching seems to suggest that two or more new aggre-

gates happened to deposit on the aggregate at the top of the tree. But when some quantity of gelatin was first added into the solution, and then poured on a glass plate, a slightly different form of the growth was observed. As shown in Fig. 5 branching was not so remarkable as in the former case. This will be due to the fact that the gelatin increased the viscosity of the solution and thereby reduced the mobility of the aggregates. In this state the chance that two or more aggregates deposit on the one and the same aggregate became smaller and consequently the main course traced out by the crystallization would have fewer branches. In some case it was observed that a branch was formed by a discontinuous arrangement of crystal fragments (Fig. 6), and this can be explained in a similar way.

Summary

1. Modes of crystallization of potassium bichromate on a glass plate and on a gelatin film were described.
2. An explanation of the formation of figures produced by the crystallization was given.

In conclusion, the writer wishes to express his thanks to Prof. T. Mizuno for the interest he has taken in this work.

On the Limiting Size of Colloidal Particles in a Brownian Motion

By

Bunsaku Arakatsu and Mitsuharu Fukuda

(Received Oct. 20, 1919)

When minute particles are in suspension in water, they are bombarded by molecules of liquid moving in very irregular ways. The force due to the impacts is resisted by inertia of the particles and viscosity of the medium. Brownian motion takes place when the former overcomes the latter, and the motion becomes less pronounced as the size of the particle gets larger and the viscosity increases. In his book on colloidal solution, Burton¹ states that particles cease to move when the diameter exceeds about 4μ , but as to the nature of the solution and the viscosity of the medium nothing is stated. In one of our experiments with silver, particles about 2.5μ in diameter were found to be in a state of rest, while in gamboge sol, vivid motions were observed even in greater particles. This led us to study the subject more minutely.

An ultra-microscope used in the present experiment was one provided with a cardioid condenser, and rays from a carbon arc were sent through a water chamber to the condenser. The apparent sizes of the particles were measured on an ocular micrometer scale whose one division was found to be 2.25μ in the object plane of the microscope. The colloidal solutions used in this experiment were prepared by Bredig's method, the metals pulverized being gold, silver, copper, cadmium, zinc, tin, magnesium, nickel, aluminium, and tungsten; beside these, mercury suspension in water was also used. A drop of

¹ The Physical Properties of Colloidal Solutions. p. 66.

sols thus prepared was put between a pair of clean microscope cover glasses, and the microscope was focussed on a certain plane midway between them, the room temperature being about 10°C . throughout the experiment.

Of the particles in a state of rest, the smallest one was sought for, and this was then brought by centering the objective into such a position as to be measured by the ocular micrometer scale. This was then watched carefully and if any measurable displacement was noticed within a few minutes, this particle was rejected and another was again sought for. If no displacement could be detected within a few minutes, the diameter of the particle was measured, and then another particle was taken up, and the process repeated *ad lib*. For each sol about thirty such particles were measured and an example of such a measurement is given below :

For Au-sol (in μ).

2.5	2.7	2.7	2.7	2.6	2.9	2.5	2.7	3.0
2.7	2.5	2.5	2.7	2.7	2.3	2.5	2.7	2.9
2.9	2.5	2.7	2.5	2.5	2.7	2.7	2.5	2.7
2.7	2.7	2.9						

Thus 2.7μ seems to be the limiting size for gold sol.

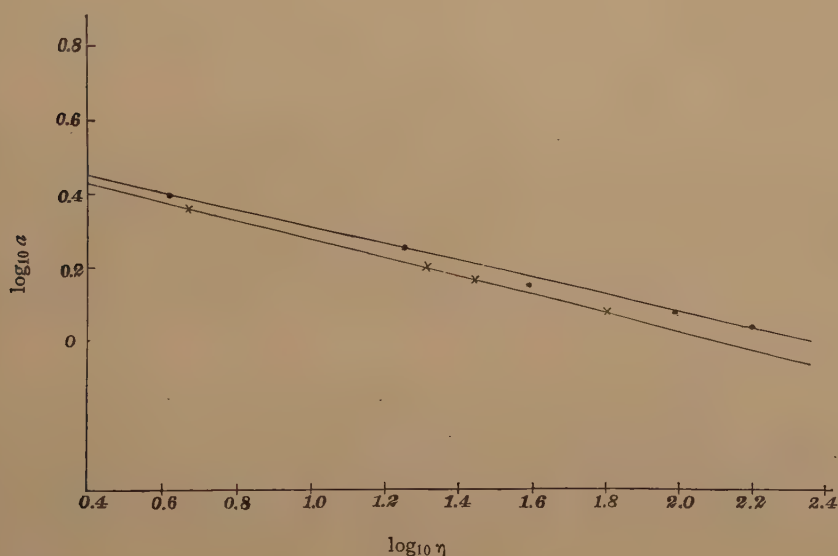
With other sols such as platinum, silver etc. limiting sizes were found to be almost the same as that for a gold. The following table shows these values for each sol thus measured.

Metals	Wo	Pt	Au	Ag	Cu	Al	Ni	Hg
Diameter in μ	2.7	2.5	2.7	2.5	2.7	2.7	2.5	2.3

The mean of these values is 2.6μ . For Cd, Zn, Sn and Mg particles were generally small and no measurement could be effected. So far as this experiment is concerned, metallic particles, whatever be their nature, placed in suspension in water, will take the Brownian motion, provided their sizes are less than about 2.6μ . This value, however, depends, of course, upon the viscosity of the continuous phase.

The relation of this limiting size of particles to the viscosity of the continuous phase was studied in the following way. It is known that sols have viscosities very slightly higher than those of the media, so that viscosities of sols may, at a close approximation, be taken to

be those of the media. In our experiments viscosity was varied by adding a concentrated solution of sugar or glycerin into the sol and the viscosities of the sols thus treated were measured by a viscosimeter. A drop from such a solution was examined under the ultra-



microscope and the limiting size was determined in the way described above.

The sols used in this experiment were of gold and copper and the result obtained is given in the following table.

Gold sol.			Copper sol.		
Viscosity: η	Limiting size: a	$a \eta^{0.229}$	Viscosity: η	Limiting size: a	$a \eta^{0.249}$
4.2	2.5 μ	3.5	4.7	2.3 μ	3.4
17.7	1.8 "	3.5	20.2	1.6 "	3.4
38.8	1.4 "	3.3	27.5	1.5 "	3.4
97.3	1.2 "	3.4	62.5	1.2 "	3.4
155.0	1.1 "	3.5			

In the annexed figure the logarithm of a was plotted against the logarithm of η , the mark $\bullet$ representing the values for gold sol and $\times$ for copper sol; thus fine straight lines are obtained, and con-

sequently, so far as the present experiment is concerned, we get the following relations for gold and copper respectively.

$$a\eta^{0.229}=3.5,$$

$$a\eta^{0.249}=3.4.$$

Summary.

1. The limiting sizes of colloidal particles performing a Brownian motion were studied for various metal sols.

In Bredig's colloids, this size is about 2.6μ for all the metals examined.

2. The relation between the viscosity of the sol and the limiting size was studied.

In conclusion, the writers' cordial thanks are due to Profs. T. Mizuno and M. Kimura for their kind guidance.

Optical Properties of Japanese Millet Jelly

By

Mitsuharu Fukuda

(Received Oct. 20, 1919)

The writer examined indices of refraction, the absorption spectrum and the rotatory dispersion of a Japanese millet jelly, and the results obtained thus far will be given below. The Japanese millet jelly is a mixture of maltose, glucose, dextrose, etc. The jelly used in the present experiment was prepared by a factory in Kyoto, and is known as "Ôgon Ame." It is a very viscous and transparent substance, its colour is slightly yellow like Canada balsam and its specific gravity is about 1.43 at 24°C.

Indices of Refraction.

Refractive indices of this substance was determined by the method of minimum deviation. The substance was poured in a hollow prism having plane parallel plates on both sides of the refracting angle ($62^{\circ} 25'$). This was kept still until the whole got optically homogeneous. It took three days to attain this state. The prism was then placed on the table of a Lang's spectrometer, and angles of minimum deviation were measured for lights of different wave lengths given by a mercury arc lamp, a hydrogen tube and a sodium flame. The refractive indices were calculated by the usual formula, and the values are given in the following table.

Wave lengths.	Indices.
---------------	----------

6563 A	1.495
--------	-------

5893 A	1.497
--------	-------

5780 A	1.498
5461 A	1.499
5359 A	1.507
4063 A	1.511

It will be observed that indices of this millet jelly are approximately equal to those of benzene.

Absorption Spectrum.

The jelly shows a slightly yellow colour when examined by transmitted light; this suggests that it absorbs light in the blue violet region of the spectrum. The absorption spectrum of a thin layer of this substance was examined with a small quartz spectrograph. The jelly was put between two quartz plates separated by a wire ring, and light from an iron arc was projected through this cell on the slit of the spectrograph and the absorption spectrum was thus photographed. Exposures of different times were given on one plate one above the other, and positions of maximum absorption were determined. It was observed that a slice of jelly of 2.4 mm. thickness completely cuts off the light from $\lambda 330 \mu$ to the extreme ultra-violet, and slightly absorbs it in the region about $\lambda 450 \mu$, while a thickness of 0.82 mm. of the *Ame* transmits weakly at the region from $\lambda 225 \mu$ to $\lambda 260 \mu$ and strongly from $\lambda 280 \mu$ up to the visible region.

Rotatory Dispersion.

As the millet jelly is a complex mixture of optically active substances, it has the property of rotating the plane of polarization of incident light. This is simply seen by looking through the substance in a crossed nicol. The amounts of the rotation for lights of different wave lengths were determined by a spectroscope. The light from an arc between iron and cored carbon was projected, through a polarizing nicol, a tube containing the jelly and an analysing nicol, on a slit of a grating spectroscope. On turning the analyser, a dark band entered at one end of the spectrum and passed slowly towards the other as the nicol was rotated, showing that different lights suffer their own amounts of rotation. To determine the positions of this dark band, lines were observed with an eyepiece through the spectroscope and the amounts of rotation for several lights were thus determined. In

the following table, φ gives angles of rotation per 1 mm. of the millet jelly, minus sign indicating that the rotation is laevo.

λ	6439	6122	5893	5857	5590	5270
φ	-1°·5	-1°·7	-1°·9	-1°·9	-2°·1	-2°·3
λ	5189	4878	4580	4440	4300	4230
φ	-2°·5	-2°·8	-3°·2	-3°·5	-3°·7	-3°·9

Thus the Japanese millet jelly rotates the plane of polarization in the negative direction, the amounts of the rotation per 1 mm. being 1°·5 for H_{α} .

Summary.

1. Indices of refraction of a Japanese millet jelly were determined, the value for sodium light being 1·497.
2. Absorption spectrum in ultra-violet region was studied.
3. It was found that the substance rotates the plane of polarization to the left, amount of the rotation per 1 mm. thick being 1°·5 for H_{α} .

In conclusion, the writer wishes to express his thanks to Prof. M. Kimura for his kind guidance.

Vol. IV, No. 4, Published June 30th, 1920.

Price - - - Yen 2.30

These Memoirs are on sale at

MARUZEN COMPANY, LTD.

TOKYO, OSAKA, KYOTO, FUKUOKA & SENDAI.

大正九年六月廿七日印刷

大正九年六月三十日發行

編纂兼發行者 京都帝國大學理學部

印刷者 大久保秀次郎

東京府北豐島郡巢鴨町三丁目十番地

印刷所 株式會社 東京築地活版製造所

東京市京橋區築地二丁目十七番地

賣捌所 丸善株式會社

東京、大阪、京都、福岡、仙臺

CONTENTS.

The Spectrum of Bromine I. Line and Band Spectra, Lines of Arc and Spark Types and the Relations between the Lines.	
By Masamichi Kimura	127
The Spectrum of Bromine II. Line Structures and the Zeeman Effect.	
By Masamichi Kimura	139
On the Distribution of Charged Ions in the Path of an Electric Discharge through a Tube Containing Bromine Vapour.	
By Masamichi Kimura	151
Studies of the Spectrum of Chlorine I. Emission and Absorption Spectra.	
By Masamichi Kimura and Mitsuharu Fukuda	155
Studies of the Spectrum of Chlorine II. The Influence of Magnetic Field upon Spectral Lines of Chlorine.	
By Masamichi Kimura and Mitsuharu Fukuda	159
Unilateral Conductivity of Tubes having a Salt Electrode.	
By Masamichi Kimura and Jun-ichiro Nagahata	163
A Short Note on the Arc and Spark Lines of Iodine.	
By Masamichi Kimura	167
Electrical States of Iodine Vapour when emitting Line and Band Spectra.	
By Komataro Makino	169
Figures produced by Crystallization of Potassium-bichromate.	
By Masamichi Kimura	173
On the Limiting Size of Colloidal Particles in a Brownian Motion.	
By Bunsaku Arakatsu and Mitsuharu Fukuda	179
Optical Properties of Japanese Millet Jelly.	
By Mitsuharu Fukuda	183
